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COSMIC LIFE FORMS

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Abstract

We propose that the first principle of biology is a useful guide in exploring cosmic life forms. Moreover, it determines the basic prerequisites of life in material-independent form. Starting from the Bauer principle (BP), we made explicit its content, and found that the Bauer principle is mediated by virtual interaction (VI) which generates biological couplings (BC) opening up an enormous realm of biologically spontaneous reactions. With the help of biological couplings, it becomes possible that the organism self-initiate systematic investment of work ΔW against the equilibrium, which would otherwise necessarily be approached on the basis of the given initial state and the laws of physics. Therefore, the essence of life can be formulated as the following: the Bauer principle (BP) is manifest in virtual interactions which generate biological couplings leading to investment of work ΔW that generates thermodynamically uphill processes increasing extropy Π ($\Delta\Pi > 0$); compactly, BP→VI→BC→ ΔW→ΔΠ. We point out that generation of lawful algorithmic complexity is a fundamental characteristic of life (Grandpierre, 2008). Applying the Bauer principle for the Sun, we found that the Sun is a living organism. We are led to recognize a cosmic life form in stellar activity cycles. Then we generalized the Bauer principle and found new kinds of cosmic life forms like the microscopic, intermittent and hidden life forms. We found that the first principle of biology is able to be manifest in the whole universe through virtual interactions. This result led us to recognize a new cosmic life form present in the vacuum that we call universal life.

Key words: most general law of biology – Bauer principle – lawful algorithmic complexity of solar activity – universal life

1. Introduction

Recently astrobiology has become main foci of modern science. In 1996, the Astrobiology program was added to NASA’s lexicon. (Dick and Strick, 2004, 19) “With the advent of the means to explore space, the prospect of developing a truly universal science of biology now seemed possible for the first time.” (ibid, 2) Similarly as the research of stellar physics plays a significant role in understanding our Sun, the research of cosmic life is of fundamental importance for the scientific understanding of what life is. We point out that being imaginative in exploring cosmic life forms will be facilitated if helped by exploring the most universal aspects of biology. If we base our exploration of cosmic life forms to the most general principle of biology, a whole list of yet unimagined cosmic life forms will become closer to us. It appears the universe itself can offer much wider perspectives for exploring the nature of life. This means that we do not consider life as being restricted to protein-based life forms; yet the basis of defining general life is specified by the first principle of biology: the Bauer principle (see below).

2. Life forms are manifestations of the biological principle

Life on Earth shows extreme variability in forms and behavior. A physical object like a falling stone falls always in the same manner from the Pisa tower. In contrast, living organisms can behave very differently even within the same conditions. Moreover, living organisms show a behavior profoundly divergent from the physical one. *We define physical behavior as the one governed by the laws of physics, with the given initial conditions* (boundary conditions included). Similarly, *we define biological behavior as the one governed by the Bauer principle, with the given initial conditions*. The difference between biological and physical behavior can be demonstrated by an extended Galileo experiment in which a living bird dropped from a height follows a trajectory characteristically different from the trajectory determined by the free falling stone.

At present, the theoretical description of the most general laws of biological behavior seems to be unavailable. In the last decades, the general belief has been that all phenomena of any systems are determined by bottom-up laws of physics, ultimately, the action principle, governing the material building blocks of the given system. Nowadays the general view of scientists is that biological laws do not exist, but if they did, they would be mere byproducts of physical laws, and the reason for the different behavior of living organisms lies in their intractable complexity (Vogel and Angermann, 1988, 1). At variance with these widespread views, theoretical biology as an exact science has been founded by Ervin Bauer on the basis of the universal and invariable characteristics of living organisms (Bauer, 1935/1967).

Recently, Popa (2004, 170–172) presents a whole list of material-independent signatures of life. Such signatures are, for example, the recovery of energy lost by the living organism in performing work on itself, as internally controlled by specific mechanisms; that life forms use this energy to control their internal entropy level; the target-oriented nature of energy transduction, which is related to couplings that must exceed a certain minimal negentropic level in order to occur. As we will show here, the common characteristics of all life forms are rooted in the existence of the biological principle.

3. The biological principle acts on possibilities left open by physics

The bottom-up approach of physics starts from material building blocks plus physical laws. Yet it is insufficient and incompetent in a biological context to produce a model that explains such elementary biological processes as the bending of a finger. There are not physical equations that can determine the time-dependent behavior of my finger which I will intend to bend in the next moment, even if it would be possible to give all the positions of the elementary particles in the initial state. Actually, there is more to nature than elementary particles plus physical laws. Besides complexity, biological behavior also enters to the scene.

In physics, any problem can be regarded as definite only if the boundary conditions representing the connection of the system are given; otherwise the differential equations cannot be solved. These conditions in physics are usually external. In contrast, in living organisms the changes initiated within the organism by the living organism itself govern behavior. This means that in biology the internal and time-dependent conditions are decisive. The same body can behave very differently within the same conditions.

It is a general view that life can perfectly well emerge from the laws of physics plus accidents (cf. Gell-Mann, 1995). Indeed it seems that physics can describe any phenomenon by boundary conditions (describing the initial state) plus the laws of physics, with the qualification that the source of all occasional physical indetermination is chance. Actually, any physical state can be reached from a previous state with the help of chance. Nevertheless, biological behavior shows a remarkably consequent character that profoundly differs from the physical case, as the example of a living bird dropped from the Pisa tower indicates. The characteristic property of the trajectory of a living bird dropped from a height is that it regains, approximately, its original height. In general, biological behavior leads to the regeneration of the distance of the organism from thermodynamic equilibrium.

Thermodynamic systems are defined as consisting of statistically independent subsystems (Landau and Lifshitz, 1959). Now the Second Law of thermodynamics tells us that all isolated thermodynamic systems will develop towards equilibrium (ibid., 8. §). Systems in thermodynamic equilibrium have independent, separable subsystems and so they manifest chance (e.g., thermal fluctuations) and necessity (the systems consisting of a large number of separable subsystems are governed by the determinate laws of physics). They cannot show *organized* changes, since their interactions are statistically independent and chaotic (ibid., 1. §).

"Thermodynamics is the study of the macroscopic consequences of myriads of atomic coordinates, which, by virtue of the statistical averaging, do not appear explicitly in a macroscopic description of a system." (Callen, 1960, 7) In terms of complexity science, the random interactions of independent subsystems have no *lawful algorithmic complexity* representing the algorithmic complexity of the laws of nature (in the followings, shortly: algorithmic complexity), since their effects can be averaged out. In contrast, living organisms manifest an extremely high algorithmic and genetic complexity. Therefore the – let us use that term for the moment in a biological context – "subsystems" of living organisms do not form a pure thermodynamic system, and so their interactions cannot be averaged out to thermodynamic parameters like temperature or entropy only. In respect of biological behavior, living organisms are not thermodynamic systems. In living organisms, after averaging out all statistically chaotic interactions, something remains, and this something has a fundamental importance in understanding biological organization. It seems inevitable to allow that the non-randomness of living organisms' subsystems is directly related to their observed, profoundly non-physical behavior. Actually, living organisms do not have subsystems comparable to the ones of a thermodynamic system, since biological organization extends from the level of the whole organism downwards to the level of molecules and beyond. This means that systematic dependences exist between the entities existing at the molecular, submolecular and supramolecular levels of biological organization. These systematic dependences represent *systematic* interactions and couplings.

It seems to be clear that if a systematic coupling exists between the subsystems in a way that determines the behavior of these subsystems, we indeed leave the realm of physical systems and enter to the field of cybernetics. It is important to keep in mind that the behavior of living organisms is much subtler governed than cybernetic machines. The non-random mechanical couplings between the components make it possible to show definite functions manifested in refrigerators and airplanes. Actually, the behavior of living organisms is also characteristically non-random. Their mechanical couplings (like that of the bones of an athlete) are originated in subtle biological couplings, determining the contraction of its muscles. These subtle, non-random biological couplings act between the myosin and ATP molecules, between the muscular cells and the global organism of the athlete. At the deepest level, biological couplings are related to couplings between thermodynamically downhill (exergonic) and uphill (endergonic) biochemical reactions. (Green and Reible, 1975; Purves et al., 1992, 1, 137) For the sake of precision, we note that thermodynamically downhill processes are defined here on the global level with the thermodynamic state variable extropy, while endergonic and exergonic reactions are qualified at the level of individual biochemical reactions.

The basic fact of life is the avoidance of thermodynamic equilibrium, which corresponds to death. Living organisms live by utilizing their nonequilibrium energies. Their functions require high-level forms of energy at their input and low-level forms of energy at their output. Thermodynamic aspects of living organisms are accompanied by equilibration or downhill processes. In order to avoid equilibrium, living organisms must continuously realize thermodynamically uphill processes compensating the downhill ones. Life in this respect is the consequent activity against thermodynamic equilibrium. Therefore, living organisms have a fundamental characteristic in compensating the equilibration downhill processes by uphill ones. The regular appearance of uphill processes may seem as contradicting the Second Law, but only when ignoring the simultaneous downhill processes. Most of these downhill processes also serve in useful biological roles, for example, dissipating "low quality" thermal radiation. This dissipation is required to balance the incoming high quality energy; and the low quality (e.g. lower temperature) of the output thermal radiation offers a net gain of useful energy for the organism. Definitely, only with the help of biological couplings between the subsystems can the organism make its biological behavior so different from the physical.

4. Formulation of the Bauer principle in elementary sentences

Regular compensation of equilibration processes with uphill ones requires a systematic work on the internal structure of the organism. In order to initiate uphill processes, regenerating nonequilibrium structures, gradients and potentials, living organisms must be able to work continuously against the thermodynamic equilibrium that otherwise ultimately would be reached given the actual instantaneous state of the organism on the basis of physical laws. This simplified chain of thoughts points towards the Bauer principle. The Bauer principle in its full form tells that "T*he living and only the living systems are never in equilibrium, and, on the debit of their free energy, they continuously invest work against the realization of the equilibrium which should occur within the given outer conditions on the basis of the physical and chemical laws.*" Bauer had shown that this is the first principle of biology, since all the fundamental phenomena of life can be derived from it (Bauer, 1935/1967, 51).

Let us formulate this compact definition in elementary statements. Requirement (a) tells that living systems are never in equilibrium. Requirement (b) tells that on the debit of their free energy content, they continuously invest work against the realization of the equilibrium which should occur within the given outer (initial and boundary) conditions on the basis of the physical and chemical laws. We can break requirement (b) into (b1) requiring continuous and self-initiated work investment ΔW in order (b2) to initiate a behavior differing from the one determined by the laws of physics and chemistry. In our understanding, (b1) and (b2) tells that the investment of work ΔW must be thermodynamically uphill. Moreover, (b2) tells that if the considered system has elementary constituents with coordinates x_i, their spatial coordinates R have to differ in time from the one expected on the basis of physical and chemical laws, given the initial conditions. This means that the spatial trajectory of the constituent parts differ from the physical one by an amount $\Delta R(x_i, t)$. It is not allowed to simplify the Bauer principle to its requirement (a), or misinterpret it as requiring only the "avoidance of thermodynamic equilibrium". As our detailed analysis clearly shows, only the simultaneous fulfillment of all the three requirements (a), (b1) and (b2) is equivalent with the Bauer principle.

It is usual to consider that in physically spontaneous processes entropy can only increase. Actually, when a piece of matter exists in a colder/hotter environment, its entropy S will decrease/increase in the equilibration. Moreover, the free energy is defined through the change of the chemical potential relative to the standard state corresponding to $T = 298.16$ K and $p = 1$ atm (Haynie 2001, 81). Therefore, the change of the entropy ΔS (and ΔG, the Gibbs free energy) of the system is not always a good indicator of thermodynamically downhill processes occurring within the considered system. Instead, thermodynamically downhill or equilibrating processes of physico-chemical systems can be characterized by the decrease of extropy Π, the distance from equilibrium (Martinás and Grandpierre, 2007) of the system ($\Delta\Pi<0$). We define thermodynamically uphill processes here as processes in which the extropy of the system increases, $\Delta\Pi>0$. Extropy is measured relative to the environment; therefore it always decreases in equilibration or downhill processes.

Systems receiving positive extropy flow from their environment, like self-organizing physical systems, or like living organisms, can manifest structure formation. In terms of extropy, one can formulate the Bauer principle as requiring an investment of work ΔW in order to initiate uphill processes $\Delta\Pi>0$ compensating the equilibrating processes $\Delta\Pi<0$ occurring in the system.

Now let us consider how the Bauer principle applies to physical self-organizing systems. Self-organizing physical systems like Benard-convection cells in a fluid heated from below have constant energy supply (through incoming energy flow from below) and extropy supply (they receive higher quality energy at their input and release lower quality energy at their output) and so their distance from thermodynamic equilibrium can be constant. The permanent transformation of higher quality energy into lower quality energy can be described as an extropy flow through the system maintaining the structure and internal organization in the cell balancing the downhill process of radiated heat. For such systems, the change of extropy within the system can be practically zero, $\Delta\Pi \sim 0$, *without any investment of systematic work by the Benard cells themselves.* Instead, their behavior is described by the laws of physics. This means that Benard cells do not fit the (b1) and (b2) requirements of Bauer principle.

We define a process as *thermodynamically spontaneous* if it occurs spontaneously, without any non-thermodynamic influence or intervention. Equilibrating processes occur by themselves, they are thermodynamically spontaneous. In comparison, *we define a process as biologically spontaneous if it occurs spontaneously in the presence of biological couplings*. Active transport regenerating a gradient is an uphill process; it cannot occur spontaneously in thermodynamics but can occur spontaneously in biology in the presence of suitable conditions and biological couplings. Now let us compare the range of physically spontaneous and biologically spontaneous processes. Although physical spontaneity is wide-ranged, including spontaneous emission, spontaneous absorption or spontaneous energy focusing at the wheel of a breaking car, biological spontaneity is much more wide-ranged, since it includes an astronomically rich realm of uphill processes which cannot occur spontaneously in thermodynamics. Therefore, systematic work investment also cannot occur spontaneously in thermodynamics. On the other hand, systematic work investment is a basic characteristic of living organisms required by the first principle of biology.

Complexity enters into the scene because *systematically directed useful work* is possible only by systems having a significant rate of algorithmic complexity. This is why machines require delicate planning and realization of a task-solving procedure having an algorithmic complexity. All machines serve some need or function. To obtain biologically useful, thermodynamically uphill work, living organisms must have extremely large algorithmic complexity. The first principle of biology holds that biologically useful work is exerted spontaneously in any part of the system in such a way as to promote the biologically optimal range, which corresponds to the characteristic distance of the organism from equilibrium.

Let us consider a simple example. A burning candle does not invest work on the debit of its free energy content. It does not have algorithmic complexity content in its structure. It does not fulfill requirements (b1) and (b2), therefore it cannot be regarded as living.

5. On the nature of biological couplings

We indicated that biological couplings, in general, connect nonequilibrium energies. “Reactions that consume energy [endergonic reactions] can occur in living organisms only because they are coupled to other reactions that release it [exergonic reactions].” (Purves, Orians and Heller, 1992, 1) All biological transport is based on biological couplings (Harvey, Slayman 1994). Biological coupling can occur due to chemical coupling with metabolic reactions or by coupling physical processes to chemical processes like energy or electron transfer, isomerizations, chemical bond-breaking or formation (Sundström, 2007). Ultimately, chemical bonds can be explained by quantum electrodynamics. The basic field of quantum electrodynamics corresponds to three basic types of actions: a photon goes from place to place, an electron goes from place to place, and an electron emits or absorbs a photon (Feynman, 1985, 84-85). These basic actions correspond to radiative energy transfer, linear energy transfer and light emission and absorption, respectively. Besides radiative and linear energy transfer, fluorescence (or Förster) resonance energy transfer, proton coupled energy transfer, and many-body phenomena like energy transfer through delocalized collective excitations (Dahlbom et al., 2002) also play important role in biological organization.

We find it of basic importance that biological organization always starts from the level of the organism/cell; the overall biological viewpoint breaks down into partial processes, into an organized system of more and more partial functions at the lower and lower level of organizational hierarchy, similarly as in the case of the more closely known overall reactions of metabolism, photosynthesis and respiration (Crofts, 2007, 17). In order that all these individual reactions, contributing to more and more global functions could sum up into the global level biological viewpoint, all these partial functions at the many levels of hierarchy must be cohered. The mechanism securing the extremely fine tuning of all these partial functions must be more subtle than the biological processes themselves. We propose that the mechanism beyond the exquisite fine tuning of all these partial processes is governed by the most subtle process possible to realize in physics: by virtual interactions.

Actually, virtual interactions are governed in physics by the action principle (Feynman and Hibbs, 1965). Definitely, virtual interactions in living organisms must be governed by a separate, biological principle. We propose that biological couplings are realized by virtual interactions governed in living organisms by the biological principle.

In this way, we found that the fundamental requirements of the Bauer principle, when formulated as $\Delta W \rightarrow \Delta \Pi$, can be extended not only to $BC \rightarrow \Delta W \rightarrow \Delta \Pi$, but still further. Biological organization is initiated by the Bauer principle (BP) as manifested in virtual interactions VI, and so we can write it formally as $BP \rightarrow VI \rightarrow BC \rightarrow \Delta W \rightarrow \Delta \Pi$. Describing the complexity aspects of biological organization, we find that the deepest level of complexity of the Bauer principle is manifested in virtual interactions determining biological couplings, and these coupling processes determine the biochemical reactions representing a time-dependent series of reaction networks representing algorithmic complexity.

6. A classification of cosmic life forms

It seems that “All living organisms depend on external sources of energy to fuel their chemical reactions.” (Purves et al., 1992, 1) We found that the first principle of biology, the Bauer principle corresponds to self-initiated work of the organism; and this work requires energy. We point out that this requirement can be helpful in exploring cosmic life. Within cosmic conditions, in principle, two types of living organisms can exist, both of which must obey the Bauer principle. The difference between them is that a living organism that belongs to the first class is supplying the required energy for internal work W directly from internal energy sources under its own control. A living organism of the second class has its own internal energy sources, but on relatively long timescales, it cannot indefinitely manage without external energy sources. Certainly, living organisms depending on external energy resources need to actively explore their spatial environment; that is, they must have the ability to change their place to obtain the required energy for internal work W. The basic forms of changing place are growth and locomotion, corresponding to plants and animals.

In contrast, living organisms of the first category, which have their own internal energy sources, are not obliged to growth or locomotion, for they can regulate their access to their own internal energy sources. In comparison, a machine with an accumulator does not invest work by its own initiation, since all the work it makes is prescribed in its program which is given to it externally. Moreover, machines work in a way corresponding to the laws of physics plus the input conditions. Therefore, machines with accumulators do not qualify as living organisms, since they do not fulfill requirements (b1) and (b2).

7. On the living nature of the Sun

Now let us consider whether the Sun fulfils the Bauer criterion or not. Definitely, the Sun is a nonequilibrium system, fulfilling requirement (a). Regarding requirement (b1), we note that the systematic regeneration of solar activity in the solar cycles involves a systematic work investment. The generation of the activity forms, their quasi-cyclic regeneration during the whole lifetime of the Sun definitely fulfill requirement (b1). Regarding requirement (b2), it may seem that the Sun is overly complex, and because of this unfathomable complexity it is not possible to determine whether the behavior of solar activity corresponds to physical behavior or not. Moreover, the boundary conditions of the Sun (e.g. because of planetary motions) are continuously changing. Therefore, it seems that it is not easy to apply the conditions of the Bauer principle. We can overcome this difficulty if we find that physically unexpected phenomena show up systematically and regularly in the Sun. Actually, fundamental aspects of solar physics like solar structure and evolution are determined by the so-called Standard Solar Model (SSM). Remarkably, solar activity is missing from the SSM, and it does not follow from it. Although some consequences of solar activity like diffusion are already included into the SSM, solar activity still today represents an enigma (Grandpierre 1996, 1999, 2004, 2005, and more references therein). Regarding these considerations, on the basis of Bauer's principle we can realize that the Sun is a living organism, because it initiates a systematic work for an activity-regenerating activity that seems to differ definitely from the corresponding physical behavior, given the same initial conditions.

Definitely, the term *systematic* work refers to the lawful algorithmic complexity content of the related processes. Let us consider now some complexity aspects of solar activity.

"The prime cause of the solar cycle is a quasi-periodic oscillation of the solar magnetic field." (Ossendrijver and Hoyng, 2001). Electromagnetic field has an unlimited potential to represent complex forms. Electromagnetic fields can vary from place to place both spatially and temporally, and their complete description may require an astronomically large amount of data. In stars like the Sun, these complex structures are related to filamentary structures, current sheets, plasmoids, etc. Remarkably, all these structures can form spontaneously within stellar interiors (Grandpierre, 2004; Grandpierre and Ágoston, 2005).

A whole list of fundamental facts showing the life-like nature of the Sun has already been advanced (Grandpierre, 1996, 1997, 1999, 2004, 2005). The Sun shows an organized spontaneous macroscopic activity that is known as solar activity. Actually, solar activity is governed by the solar magnetic field; that is, it is a self-initiated activity. Solar activity has an extremely complex nature with respect to the wide variety of its forms (flares, sunspots, flocculi, coronal mass ejections, spicules, prominences, etc.), and its temporal and spatial scales. Solar activity has been shown to manifest a kind of *information* (Consolini et al., 2003).

Remarkably, the Sun has practically infinite degrees of freedom. This basic fact offers a new, wider perspective by which to consider the complex behavior of the Sun. The fact that solar activity has been present in the Sun for billions of years is, as we point out, an unusual condition for a physical system. Normally, one would expect that a thermodynamic system continuously dissipating energy and mass into its environment, like the Sun, equilibrates on its thermal timescale. Indeed, the Second Law of thermodynamics tells that any system without internal constraints storing energy in forms inaccessible to dissipation should approach thermodynamic equilibrium on the dissipation timescales. The dissipation timescale of thermal energy in the Sun is the Kelvin timescale and its magnitude is around 30,000 years. Nevertheless, solar activity regenerates the global magnetic field cyclically on a timescale of 11 years, and this cyclic activity has been going on in a timescale of 5 billion years. The problem is not only that there should be a mechanism regenerating thermal differences. In order for the Sun to be able to regenerate its cyclically disappearing magnetic field, cyclically changing sign and regenerating every ~11 years (~22 years if the polarity of the field is taken into account), the mechanism regulating the vectorial velocity space and magnetic field space must work systematically and apply in each cycle fine tuning.

We point out that in the real Sun the actual magnetic and velocity fields are highly complex. Definitely, on the basis that magnetic fields are governed by the Maxwell equations and hydrodynamic flows are governed by the laws of hydrodynamics, one would expect that they develop quasi-independently. Since the process generating magnetic field works repeatedly, and because fine-tuning is required in order to match the extremely complex velocity fields to the extremely complex magnetic field, we are led to assume the presence of a lawful fitting mechanism that acts from cycle to cycle. The consecutive and systematic variation of the field occurred already a hundred million times. Again, the hundred-million-times repeated exquisitely sophisticated co-operation of physically extremely improbable events presents a definite difference from the behavior one would expect merely on the basis of the initial conditions plus the laws of physics, fulfilling both requirements of the Bauer principle (b1) and (b2).

The fitting of the complex velocity and magnetic fields involves time-dependent internal boundary conditions that support regeneration of the magnetic activity. We propose that the fine tuning of such extremely complex fields cannot be repeated hundred million times requires without a rule or a law. It is a formidable task to modify the magnetic field and the velocity field in the whole body of the Sun from point to point just in a way that regenerates the magnetic activity forms. The solution of this task represents a significant amount of algorithmic complexity. We are led to propose that solar activity represents algorithmic complexity. Algorithmic complexity is the characteristic of man-made machines and living organisms. Since the Sun is not a man-made machine, our proposal leads to the conjecture that the Sun is a living organism. Indeed, if the Sun represents an algorithmic complexity in its activity forms governed by the magnetic field, then the information content corresponding to the algorithmic complexity of the magnetic field's variations governs solar activity. Now it is a widely accepted view that living organisms can be defined as natural systems governed by information (see e.g. Roederer, 2003; Ben Jacob et al., 2006). Now since solar activity is governed by its information content corresponding to its lawful algorithmic complexity, the Sun is a living system.

8. Experiments suggested testing the living nature of the Sun

We suggest that terrestrial plants absorbing photon flux emitted by the Sun can serve as suitable measuring devices. Photons by their very nature are suitable to manifest information since light is the par excellence carrier of information. We are wondering how can the possibility that light emitted by the Sun carries information escape due attention — other than that of Tribus and McIrvine (1971), who suggested that the Sun emits information at the rate of 10^{38} bit s^{-1} in the form of light? If solar photons carry information, and if the Sun is a living organism, than solar photons can carry information about a cosmic life form, including biologically useful information arising from the Bauer principle. Certainly, during the hundreds of million years, biological life on Earth has already figured out how to utilize the astronomically huge flow of biologically useful information reaching the Earth from the Sun. In that way, terrestrial cells did not have to start from scratch, from the physical level of algorithmic complexity. Biogenesis on the Earth seems to be facilitated enormously by the information flow present in solar radiation carrying an enormous flux of algorithmic, and, perhaps, still deeper level of complexity.

And if so, then plants could react sensitively to deprivation of sunlight. In accordance with this expectation, tomatoes grown outdoors would be found to have better biological effects than tomatoes grown in greenhouses. We propose an experiment to grow tomatoes in solarium light and compare their biological effects with control tomatoes grown outdoors.

9. Life forms bridging up the gap between life and non-life

Now we make a further step in exploring cosmic life forms by asking whether life can be continuous with the apparently inanimate world, as many scientists suggested (e.g. Nature, Editorial, 2007). We all know that highly organized life can be manifest only when suitable conditions are present. Yet there are strong arguments telling that there is no sharp boundary between life and non-life. For example, quanta in the double-slit experiment are able to orientate themselves according to the situation as a whole and behave correspondingly (Grandpierre, 2007). Therefore, it seems that quanta conduct their behavior not only according to the laws of physics but also according to the situation as a whole. We attempt here to bridge the apparent gap between living organisms and quanta with the help of a series of steps generalizing the Bauer principle, replacing the requirement of systematic investment of work by some less restrictive conditions that can actually correspond to forms of cosmic life.

Let us try to approach the most general life form by recognizing the special properties of life as we know it on Earth and try to look at what we find if we remove these special properties from the concept of life. First of all, the difference between animals and plants is that animals are able to move. Usually, plants are not motile, but are able to govern their shapes (as the Sun, too, regarding its activity forms).

The difference between a physical object and a living organism is that the living organism can select an endpoint for the action principle, like a living bird when dropped from a height, in contrast to a fallen stone that must follow the law of free fall. The fallen stone follows the least action principle, while the living bird follows the most action principle securing the maximum available distance from equilibrium. The selection of the endpoint for the most action principle produces an input for the first principle of physics securing the least action to be consumed. (Grandpierre, 2007) In order that an organism can move its parts like an animal or change its forms as a plant, it must be able to select an endpoint and govern its whole macroscopic structure towards reaching the selected state. In plants and animals, the conditions are such that they are able to realize such hierarchical organization from the global to the microlevel, continuously. It seems to be possible that there are systems in which the conditions necessary for realizing a selected macrostate through organizational processes across all hierarchical levels of organization are not present continuously. In such systems, endpoint selection cannot be realized continuously, but intermittently, or only occasionally. Microscopic and intermittent life may be present in the inorganic world in the form of occasional realization of the most action principle in microscopic processes. Hypothesizing microlife has a definite advantage of allowing life to be continuous with the inanimate world, since microlife in a physical environment without any forms of available free energy content can lead the same result as the least action principle. Clearly, if all the available free energy is zero, the maximum usable energy is identical with the minimum of it. This interpretation may explain the origin, nature and working mechanism of the least action principle, by the same token.

We may add that microlife can lead through relatively long time scales; microlife forms can produce observable macroscopic consequences in geology and astrophysics. This kind of life form may be referred to as microlife at large or hidden life. Microlife at large is different from macrolife in that macrolife organisms manifest biological behavior in their macroscopic changes like activity forms or locomotion, while microlife at large show variations only on geological or astronomical time scales.

Exploring cosmic life forms we are led to an unexpected and surprising result. This result tells that the universe may be full with cosmic life forms: stars with stellar activity cycles, intermittent life, microlife can populate the universe from cosmic clouds until stellar surfaces. If so, life can be truly a universal phenomenon, in a more full sense of the word as suspected until now.

10. On the origin of the anthropic principle of the universe

In the last decades, the fine-tuning of the fundamental constants of physics led to the wide ranged discussion of the anthropic principle (cf. Davies, 2006). We propose here a simple explanation for the fine-tuning of the fundamental constants. According to this proposal, the fundamental constants and laws of physics are in a certain sense secondary in comparison to the biological principle.

We indicated that within living organisms, it is the biological principle that acts first, and the physical principle acts only after the approximate range of biologically selected end states are determined. Considering cosmic life forms it is of importance to keep in mind that the biological principle is universal, similarly to the physical principle. Therefore, the biological principle has a fundamental cosmic aspect. If the biological principle acts first in the cosmic context, then all the material properties of the universe have to fit to biology. Our argument indicates that the thesis of the anthropic principle telling that fundamental constants of physics must fit to the existence of life is a corollary of our thesis telling that the universe is fundamentally alive and so biology is the control theory of physics.

11. On the living nature of the universe

As the observations show, the distribution of matter is favorable for the organization of matter into cosmic clouds, for the birth of the Solar System and the life on Earth. The appearance of life and humans from a gravitationally contracting cosmic cloud seems to imply an increase of algorithmic complexity. We argue that such an increase of algorithmic complexity can be regarded as an important sign indicating the living nature of the universe.

We argue that our universe consists not only from elementary particles and forces, but also from the laws and first principles of nature *governing* interactions. A basic difference between forces and the laws of nature is that forces are local and instantaneous entities, while the laws of nature governing their evolution are universal. We propose that the laws and first principles of nature connect all material systems of the universe into a unified whole. Now if the biological principle selects endpoints that are input elements to the first principle of physics, then the universe becomes unified as a biological system.

We indicated that the first principle of biology acts through virtual interactions realizing biological couplings that determine the material processes. Now if virtual interactions are ultimately controlled by biological interactions, then the vacuum has to have a fundamentally biological nature. We suggest that in this sense the vacuum qualifies as a living organism. By our argument, the biological vacuum qualifies as the ultimate cosmic life form. This cosmic life form can be referred to as universal life.

We point out that the exact definition and theoretical derivation of these cosmic life forms from the Bauer principle makes it possible to work on finding their observational signatures.

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